OPTICAL WAVELENGTH DIVISION MULTIPLEXING TRANSMISSION SYSTEM

FIELD OF THE INVENTION

The present invention in general relates to an optical transmission system. More particularly, this invention relates to an optical wavelength division multiplexing transmission system.

BACKGROUND OF THE INVENTION

In recent years, with still more expanding expectations for development of an optical communication technique to provide a high bit rate, large capacity transmission path as an infrastructure of the information-oriented society, there have been promoted global and vigorous researches and developments of high rate, large capacity optical communication systems.

On the land, an optical wavelength division multiplexing transmission system of a 10 Gb/s transmission rate using a transmission path of a 1.3 μm band single mode fiber (SMF) and a 1.55 μm band dispersion shift fiber (DFS) has come in practice.

Under the ocean, on the other hand, an optical wavelength division multiplexing transmission system of a 10 Gb/s transmission rate using a transmission path of a non-zero

dispersion shift fiber having a zero-dispersion wavelength at a 1.58 μm band has come in practice.

Generally, there occurs a transmission waveform deterioration in the optical fiber due to interaction (called SPM-GVD effect) between a self-phase modulation (SPM) and a group-velocity dispersion (GVD). Therefore, a possibly smaller value should be set as a value of the (group-velocity) dispersion to be caused by a difference in transmission time in optical fiber between optical signals different of wavelength.

However, as the wavelengths of the optical signals approach a zero-dispersion wavelength, there is an increased tendency for a four-wave mixing (FWM) to cause a crosstalk, with an increased deterioration of transmission characteristic. Therefore, the optical wavelength division multiplexing transmission requires a wavelength layout in consideration of a zero-dispersion wavelength of optical fiber.

An optical wavelength division multiplexing transmission system is disclosed in Japanese Patent Application Laid-Open Publication No. 8-97771. This conventional system uses a transmission path of a 1.55 μm band dispersion shift fiber (DSF), in which the effect of a conventional four-optical-wave mixing is suppressed.

Fig. 17 is a graph describing the principle of the

conventional system, in which signals of respective wavelengths are subject to a wavelength conversion for an interchange between wavelengths to make the optical level of crosstalk lower than specified.

At present, if two different networks (transmission paths), such as for land use and submarine use, are to be connected at a connection point therebetween, then the two different networks are electrically terminated. However, it is necessary for aiming at a practical low-cost system to implement a connection-less simplified structure for structural integration of two networks.

In the conventional system, however, optical fibers in use have different zero-dispersion wavelengths, and a direct use for transmission accompanies a crosstalk due to the SPM-GVD effect or FWM, as a significant problem.

<u>SUMMARY OF THE INVENTION</u>

The optical wavelength division multiplexing transmission system according to the present invention comprises a first optical fiber transmission path for a wavelength division multiplex signal to be input therefrom, a second optical fiber transmission path having a zero-dispersion wavelength different from the first optical fiber transmission path, and an optical repeater in which the wavelength division multiplex signal input from the first

optical fiber transmission path is wavelength-converted with respect to respective wavelengths thereof, for an output thereof to the second optical fiber transmission path.

Other objects and features of this invention will become apparent from the following description with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of an arrangement according to a first embodiment of the invention;

Fig. 2A is a graph of wavelength layout at an input side of the first embodiment and Fig. 2B is a graph of wavelength layout at an output side of the first embodiment;

Fig. 3 is a block diagram of an optical repeater 1 according to the first embodiment;

Fig. 4 is a block diagram of an optical repeater 11 according to a second embodiment of the invention;

Fig. 5 is a block diagram of an optical repeater 21 according to a third embodiment of the invention;

Fig. 6 is a block diagram of an optical repeater 31 according to a fourth embodiment of the invention;

Fig. 7 is a block diagram of another optical repeater 61 according to the fourth embodiment;

Fig. 8 is a block diagram of a wavelength converter 62 according to a fifth embodiment of the invention;

Fig. 9 is a block diagram of a wavelength converter 63 according to a sixth embodiment of the invention;

Fig. 10 is a block diagram of a wavelength converting element 111 according to a seventh embodiment of the invention;

Fig. 11 is a block diagram of a wavelength converting element 112 according to an eighth embodiment of the invention;

Fig. 12 is a block diagram of a wavelength converting element 113 according to a ninth embodiment of the invention;

Fig. 13A and Fig. 13B are graphs of wavelength layout at an input and output side according to a tenth embodiment of the invention;

Fig. 14A and Fig. 14B are graphs of wavelength layout at an input and output side according to an eleventh embodiment of the invention;

Fig. 15A and Fig. 15B are graphs of wavelength layout at an input and output side according to a twelfth embodiment of the invention;

Fig. 16A and Fig. 16B are graphs of wavelength layout at an input and output side according to a thirteenth embodiment of the invention;

Fig. 17 is a graph of wavelength layout of a conventional example.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention are explained below with reference to the accompanying drawings.

Fig. 1 shows a network arrangement according to a first embodiment of the invention. Legend 1 denotes an optical repeater having a wavelength converter, legend 2 denotes an optical fiber having a zero-dispersion wavelength $\lambda 0$, and legend 3 denotes an optical fiber having a zero-dispersion wavelength $\lambda 0'$.

Fig. 2A and Fig. 2B show examples of wavelength layout according to this embodiment. Fig. 2A is a graph of wavelength layout of an optical input signal in the optical repeater 1. Relative to the zero-dispersion wavelength $\lambda 0$ of the optical fiber 2, n waves $\lambda 1$ to λn are laid out so that the SPM-GVD effect and FWM of their wavelengths are minimized.

Fig. 2B is a graph of wavelength layout of an optical output signal in the optical repeater 1. At the optical fiber 3, this signal is wavelength-converted so as to minimize the SPM-GVD effect and FWM relative to the zero-dispersion wavelength $\lambda 0'$, and is output.

Fig. 3 shows an arrangement of an optical repeater 1 according to the first embodiment. Legend 5 denotes a wavelength selector, legend 6 denotes a wavelength converter, and legend 7 denotes a wave combiner. The wavelength selector 5 and the wave combiner 7 can be constituted with ease by

an optical filter and a photo-coupler, respectively.

The optical repeater 1 operates as explained next. An optical signal with multiplexed wavelengths $\lambda 1$ to λn is input into the wavelength selector 5. The wavelength selector 5 separates the received multiplexed wavelengths $\lambda 1$ to λn into optical signals by the wavelengths $\lambda 1$ to λn and supplies the separated wavelength to the wavelength converters 6.

Based on a control signal, the wavelength converters 6 respectively convert the wavelengths, such that $\lambda 1$ into $\lambda 1'$ and $\lambda 2$ into $\lambda 2'$ etc.. The wavelength converters 6 provide the converted wavelengths to the wave combiner 7. The wave combiner combines the wavelengths $\lambda 1'$, $\lambda 2'$, $\cdots$, $\lambda n'$ and outputs the result.

Thus, there can be implemented a connection-less simplified structure for structural integration of the two networks (transmission paths).

As explained above, an optical repeater 1 is provided between a first optical fiber transmission path 2 and a second optical fiber transmission path 3 having a zero-dispersion wavelength different from the first optical fiber transmission path 2. This optical repeater 1 wavelength-converts with respect to respective wavelengths a wavelength division multiplex signal input from the first optical fiber transmission path 2, and output the result to

the second optical fiber transmission path 3. Therefore, the SPM-GVD effect and FWM in the second optical fiber transmission path are minimized, thereby implementing a connection-less simplified structure for structural integration of the two networks (transmission paths).

Fig. 4 shows an optical repeater 11 according to a second embodiment. In this optical repeater 11, a wave divider 4 and wavelength selectors 5 are provided in place of the wavelength selector 5 in the first embodiment shown in Fig. 3. The wave divider 4 may be, for example, a photo-coupler.

An optical signal with multiplexed wavelengths $\lambda 1$, $\lambda 2$, ···, λn is input to the wave divider 4, wherefrom optical signals of all channels are likewise output to be sent to the wavelength selectors 5, where they have their wavelengths $\lambda 1$, $\lambda 2$, ···, λn selected, to be sent to wavelength converters 6. Thereafter, actions are like the case of Fig. 3.

Even with the second embodiment, there can be implemented a connection-less simplified structure for structural integration of the two networks (transmission paths).

Fig. 5 shows an optical repeater 21 according to a third embodiment. In this optical repeater 21, an optical amplifier 8 is provided after the wave combiner 7. This optical amplifier 8 compensates the loss at the wavelength converters 6, and also performs the optical amplification

wave combining.

Fig.6 shows an optical repeater 31 according to a fourth embodiment. In this optical repeater 31, the optical amplifier 8 is provided between every wavelength converter 6 and the wave combiner 7. Accordingly, amplification can be effected an even level.

Because the optical amplifier 8 is inserted after every wavelength converter 6, the gain is adjustable in dependence on a wavelength conversion efficiency of associated wavelength, thereby permitting compensation of an optical loss.

The compensation may preferably be effected of both transmission path loss and wavelength conversion loss, as shown in the optical repeater 61 in Fig. 7.

Fig. 8 shows a wavelength converter 62 according to a fifth embodiment. This wavelength converter 62 may be used in place of the wave converters 6 in any of the first to fourth embodiments. The wavelength converter 62 comprises an opto-electrical converter 9 and an electro-optical converter 10. The opto-electrical converter 9 converts an input optical signal of wavelength λi into an electrical signal. The electro-optical converter 10, based on the control signal, converts the electrical signal into an optical signal of wavelength $\lambda i'$.

The opto-electrical converter 9 may be a photo-diode,

avalanche photo-diode, photo-counter, etc. The electro-optical converter 10 can be constituted with ease by use of a semiconductor laser.

Fig. 9 shows a wavelength converter 63 according to a sixth embodiment. This wavelength converter 62 may be used in place of the wave converters 6 in any of the first to fourth embodiments. The wavelength converter 63 comprises a wavelength converting element 11 operative with a control signal to have a non-linear optical effect for converting an input optical signal λi into another wavelength $\lambda i'$. The wavelength converting element 11 may be a semiconductor optical amplifier, electric field absorption type modulator, optical fiber, or the like.

Fig. 10 shows the wavelength converting element 111, that uses a semiconductor optical amplifier, according to a seventh embodiment. This wavelength converting element 111 may be used in place of the wavelength converting element 11 in the sixth embodiment.

Legend 12 denotes a light source, legend 13 denotes a photo-coupler, legend 14 denotes an optical filter, and legend 15 denotes the semiconductor optical amplifier. An optical signal (wavelength: λi) and pump light (wavelength: λp) are combined in the photo-coupler 13, to strike the semiconductor optical amplifier 15, which then generates a new wavelength-converted optical signal (wavelength: $\lambda i'$)

by way of a four-wave mixing. Only the wavelength-converted optical signal is filtered by the optical filter 14, to be output.

Fig. 11 shows a wavelength converting element 112, that uses an electric field absorption type modulator, according to an eighth embodiment. This wavelength converting element 112 may be used in place of the wavelength converting element 11 in the sixth embodiment.

Legend 16 denotes the electric field absorption type modulator. The other elements are same as those shown in Fig. 10, therefore, their explanation will be omitted. An optical signal (wavelength: λi) and non-modulated probe light (wavelength: $\lambda i'$) from the light source 12 are combined in the photo-coupler 13, to strike the electric field absorption type modulator 16, where the probe light (wavelength: $\lambda i'$) is modulated by a mutual absorptive modulation effect of the modulator 16, and only the modulated probe light (wavelength: $\lambda i'$) is filtered by the optical filter 14, to be output.

Fig. 12 shows a wavelength converting element 113, that uses an optical fiber, according to a ninth embodiment. This wavelength converting element 113 may be used in place of the wavelength converting element 11 in the sixth embodiment.

Legend 17 denotes the optical fiber. The other elements are same as those shown in Fig. 10, therefore, their

explanation will be omitted. An optical signal (wavelength: λ i) input to the wavelength converting element 11 is combined at the photo-coupler 13 with excited light (wavelength: λ p) from the light source 12, to strike the optical fiber 17, which then generates a new wavelength-converted optical signal (wavelength: λ i') by way of a four-wave mixing. Only the wavelength-converted optical signal is filtered by the optical filter 14, to be output.

The following tenth to thirteenth embodiments are each addressed to a changing process in an optical repeater 1 (or optical repeaters 11, 21, 31, and 61), where wavelength intervals are changed from an even interval layout to an uneven interval layout, or from an uneven interval layout to an even interval layout.

The tenth embodiment corresponds to a case of changing the wavelength intervals in the optical repeater 1 from an even interval layout to an uneven interval layout.

Fig. 13A and Fig. 13B show examples of wavelength layout in the optical repeater 1. Fig. 13A is a graph of wavelength layout of an optical input signal in the optical repeater 1 provided with a wavelength converter. Relative to a zero-dispersion wavelength λ 0 of an optical fiber, n waves having wavelengths λ 1 to λ n are laid out so that the SPM-GVD effect and FWM of their wavelengths are minimized.

Fig. 13B is a graph of wavelength layout of an optical

output signal in the optical repeater 1 provided with the wavelength converter. This signal is wavelength-converted so as to minimize the SPM-GVD effect and FWM relative to a zero-dispersion wavelength $\lambda 0'$ of an optical fiber, to have wavelengths laid out at uneven intervals, thus achieving like effects to the first embodiment.

The eleventh embodiment corresponds to a case of changing the wavelength intervals in the optical repeater 1 from an uneven interval layout to an even interval layout.

Fig. 14A and Fig. 14B show examples of wavelength layout in the optical repeater 1. Fig. 14A is a graph of wavelength layout of an optical input signal in the optical repeater 1 provided with a wavelength converter. Relative to a zero-dispersion wavelength $\lambda 0$ of an optical fiber, n waves having wavelengths $\lambda 1$ to λn are laid out at uneven intervals so that the SPM-GVD effect and FWM of their wavelengths are minimized.

Fig. 14B is a graph of wavelength layout of an optical output signal in the optical repeater 1 provided with the wavelength converter. This signal is wavelength-converted so as to minimize the SPM-GVD effect and FWM relative to a zero-dispersion wavelength $\lambda 0'$ of an optical fiber, to have wavelengths laid out at even intervals, thus achieving like effects to the first embodiment.

The twelfth embodiment corresponds to a case of changing

the wavelength intervals in the optical repeater 1 from a constant value $\Delta\lambda$ to another constant value $\Delta\lambda'$.

Fig. 15A and Fig. 15B show examples of wavelength layout of the optical repeater 1. Fig. 15A is a graph of wavelength layout of an optical input signal in the optical repeater 1. Relative to a zero-dispersion wavelength $\lambda 0$ of the optical fiber 2, n waves having wavelengths $\lambda 1$ to λn are laid out at wavelength intervals of $\Delta\lambda$ so that the SPM-GVD effect and FWM of their wavelengths are minimized.

Fig. 15B is a graph of wavelength layout of an optical output signal in the optical repeater 1. This signal is wavelength-converted so as to minimize the SPM-GVD effect and FWM relative to a zero-dispersion wavelength $\lambda 0'$ of the optical fiber 3, to have wavelengths laid out at changed intervals of $\Delta\lambda'$, thus achieving like effects to the first embodiment.

The thirteenth embodiment corresponds to a case of changing the number of wavelengths in the optical repeater 1 by a branching or insertion of wavelength.

Fig. 16A and Fig. 16B show examples of wavelength layout of the optical repeater 1. Fig. 16A is a graph of wavelength layout of an optical input signal in the optical repeater 1. Relative to a zero-dispersion wavelength $\lambda 0$ of the optical fiber 2, n waves having wavelengths $\lambda 1$ to λn are laid out so that the SPM-GVD effect and FWM of their wavelengths

are minimized.

Fig. 16B is a graph of wavelength layout of an optical output signal in the optical repeater 1. This signal is wavelength-converted to have wavelengths branched or inserted to be laid out so as to minimize the SPM-GVD effect and FWM relative to a zero-dispersion wavelength $\lambda 0'$ of the optical fiber 3, thus achieving like effects to the first embodiment.

Although the invention has been described with respect to a specific embodiment for a complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying all modifications and alternative constructions that may occur to one skilled in the art which fairly fall within the basic teaching herein set forth.